Long Term in Nitrogen Loads to Galveston Bay

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Nitrogen (N) is essential for estuarine primary production, and under some circumstances a shortage of N can limit photosynthesis. Like most effects, this can be either desirable or undesirable, avoiding excessive growth or limiting essential growth. N inputs are affected in many ways by anthropogenic activities. In some estuaries, notably Chesapeake and others on the eastern coast, the decision has been made to limit N as well as phosphorus inputs from wastewater and agricultural activities. N inputs are thus important ecologically and also constitute one of the principal tools by which we "manage" estuaries, either intentionally, as has been the case in the Chesapeake, or less directly, as has been the case in Galveston Bay.

For the 1991 State of the Bay Conference, some of the authors of this paper analyzed N loads to Galveston Bay over time, using published USGS flow and quality records, point source monitoring data from the City of Houston, and other sources. With the information available, it was estimated that total-N loads to Galveston Bay had peaked about 1970 and have since declined to roughly the level that was estimated for 1940. Figure 1, taken from the original paper, illustrates the findings of that work. The key points in the analysis of N input changes over time were:

1. Increase in runoff N levels presumed to be associated with population growth,
2. Observed reductions in major tributary concentrations and loads with reservoir development, and
3. Observed reduction in N inputs from higher levels of wastewater treatment starting in the late 1960's and early 1970's.

The 1991 analysis predated the GBNEP work, and the various characterization studies performed as part of the NEP process have added greatly to the available knowledge. One major study, the Ward and Armstrong (1992) characterization of trends in water and sediment quality, found statistically significant declining trends in ambient bay N levels that appear to be consistent with the reduced N inputs found over the same time period. In addition, the same study found indications of a significant decrease in the levels of chlorophyll a and total organic carbon (TOC) in the main body of Galveston Bay.

Point source loads to Galveston Bay were investigated during the GBNEP process by Armstrong and Ward (1993). Their study found total N loads from point sources to be 8,425 Metric Tons per year (MT/yr), reasonably close to our 1991 estimate of 9,200 MT/yr. Nonpoint source loads were estimated for the NEP by Newell, et. al. (1992). They estimated the average nonpoint source total N load for the entire watershed to be 23,128 MT/yr, somewhat larger than the earlier estimate of approximately 12,400 MT/yr. However, when the very large differences in methodologies (Newell et.al. used literature Event Mean Concentration data to estimate loads) are considered, this difference is probably not significant.

The US Geological Survey (USGS) (1994) assessed trends in water quality data for watersheds in Texas and found that there had been a problem with analytical methods used to measure ammonia nitrogen. After correcting for the problem, they found significant declines in the concentrations of ammonia+organic nitrogen and ammonia-N in the upper Trinity River watershed. The USGS (1996) looked at nutrient input trends along the entire Gulf coast. One finding was an insignificant increasing trend in total-N at the Romayer gage (Trinity below Lake Livingston) that was the result of an apparent increase in flow. There was no significant change in total-N concentration in the period of record.

In addition to the NEP and USGS work, major contributions to the topic have been made by the Bays and Estuary Freshwater Inflow Needs studies produced by the Texas Water Development Board (TWDB) and the Texas Parks and Wildlife Department (TPWD). Brock et. al. (1996) of the TWDB produced a more detailed nutrient budget for Galveston Bay, using data from 1988-90. After adjustments were made to obtain a zero balance, the key components of their long-term nitrogen budget included:

INPUTS	AMOUNTS (MT/YR)
Median Inflows	30,386
Wastewater	7,300
Direct Rain	700
Nitrogen Fixation	560
Entrainment from Gulf	1,749
TOTAL INPUTS	40,695
OUTPUTS	
Advection to Gulf	9,752
Entrainment to Gulf	24,460
Transfer to Fisheries	1,065
Sediment Accumulation	2,251
Denitrification	3,167
TOTAL OUTPUTS	40,695

This budget reflects considerable effort in estimating inflows and the major processes involving nitrogen. The budget was ultimately considered in calculations of long-term nitrogen and freshwater inflow needs for the system.

Several points are worth noting in this budget in relation to other estimates. One is that the inputs from inflows of over 30,000 MT/yr is somewhat larger than estimated in other studies.

At the same time it is important to note that neither this nor other studies include the effect of detrital input (leaves, branches, and anthropogenic material such as paper). Some studies have suggested that these "transported solids" that are larger than can be easily sampled, or which preferentially stay near the bottom of a moving stream, can represent a significant fraction of the total input during higher flow events.

Another major point that must be recognized is that year-to-year variations in inflows can greatly affect nitrogen inputs. All the values discussed above circa 1990 are estimates of median or typical conditions.

PROCESSES AFFECTING CHANGES IN N LOADS

The major topic considered in this paper is the temporal trend in nitrogen input. Many changes have occurred in the Galveston Bay watershed since intensive settlement began in the mid-nineteenth century. The processes with potential to affect N inputs include: Agriculture, Air Deposition, Gulf Exchange, Reservoir Development, Urban Development and Runoff, Wastewater Volume and Wastewater Quality. The following sections discuss changes that may be relevant to each area.

Agriculture - The area under row crop cultivation increased during the 19th and early 20th century, with major cotton growing areas in east Texas, but has steadily declined since the mid 20th century. In the last 30 years in particular there has been a decrease in row crops and rice and a corresponding increase in forested and grassed area. A substantial portion of the forested area is used for silvaculture. Figure 2 shows crop acreage for a representative sample of counties in the watershed (Brazoria, Chambers, Freestone, Liberty, Tarrant, Walker, and Wise) for the years 1968, 1972, 1985 and 1996. A general pattern of decline is evident. Only Liberty County showed any increase in acreage, and that was quite small in recent years.

Air Deposition – Extensive fossil fuel use has in this century has greatly increased the amount of oxides of nitrogen (NOx) released to the air. However, in the last 10-20 years there have been major improvements in emission controls, reducing the NOx emissions. These include requiring catalytic converters on auto exhausts and requiring so-called "Low NOx Burners" on new stationary sources. At this writing it was not possible to quantify the effects, but a reduction in NOx emissions is expected.

Gulf Exchange - In the N balance presented by Brock et.al. (1996) most of the N that enters the bay leaves through the Gulf inlets via direct flow and tidal exchange. One of the major changes that has occurred in Galveston Bay since the turn of the century has been the expansion of the Gulf inlets and channels to accommodate navigation. This has improved the exchange of water with the Gulf and along the main axis of the bay. This improved exchange has several effects including flushing N out of the Bay more rapidly and reducing the duration of low salinity periods following heavy inflows. More rapid removal of N from the system lowers average concentrations, which is equivalent to a reduction in input. The last change in the navigation channel dimensions was in the early 1960s, but a small increase is planned in the next few years.

Reservoir Development – Reservoir development in the watershed has been substantial, as can be seen from Figure 3. There have been no major reservoirs in the immediate vicinity of Galveston Bay during the nineties, and the rate of reservoir completion appears to have slowed but not stopped. Nevertheless, because reservoirs are quite effective in trapping particulate matter, and also remove dissolved N through plant uptake, they play a major role in reducing N loads to Galveston Bay. While the rate of major reservoir construction seen during the 1950-80 period is not likely to occur again, there is an increasing trend to construct smaller flood detention and quality enhancement structures in developing areas.

Urban Runoff - There has been substantial growth in the Houston and Dallas metropolitan areas in the decade of the nineties that has undoubtedly increased the volume of runoff. However, the incremental area is not a large percentage of the total watershed. However, any difference in the quality of runoff N concentration cannot be supported with the kind of runoff data we have available. Most of the land development in metropolitan Houston is well to the west of the Bay, where runoff goes to tributaries of the Houston Ship Channel. The channel functions as a large "wet pond" BMP, and the settled material is periodically dredged and placed in confined upland disposal areas. Dredging records analyzed during the 1980's (Wastewater Strategy Study, 1988) indicated that about 500 MT/yr of N is removed from the Bay by this process. This amount may have increased to some degree in response to the increased developed area. Other tributaries such as Clear Lake and Dickinson Bayou provide a similar stormwater runoff function.

Wastewater Volume - Since 1990 there has probably been an increase in domestic wastewater flow, reflecting population growth in urban areas, but no major change in industrial flows.

Wastewater Quality - Between 1970 and 1990 there was a major increase in nitrification, with City of Houston effluent going from 3% nitrate to 86% of the N in the oxidized form. Since 1990 there has been a continued increase in the level of wastewater treatment for both domestic and industrial sources. Higher levels of wastewater treatment reduce the quantity of ammonium-N and organic N and increase the nitrate-N levels. This has two effects in the treatment plant, and a major effect after the nitrate leaves the treatment plant. First, with greater treatment reducing the levels of ammonium and organic N, more of the effluent N is transformed into biosolids and thus removed from the effluent stream. Second, higher levels of nitrate-N in the plant can be easily removed by denitrification. This can be done either accidentally or deliberately by reducing the amount of air supplied to the plant. If done by design in biological nutrient removal, very high levels of nitrogen removal can be achieved. Both processes have the effect of reducing total N in the effluent. This can be seen in City of Houston effluent data in the 1990s in Figure 4. The flow has stayed nearly constant despite significant annexations, probably reflecting reductions in sewer infiltration and inflow. The major change has been the gradual reduction in the nitrate-N concentration that has been responsible for the reduction in the total-N treatment plant discharges. Note that with the bulk of the effluent N in the nitrate form, it is subject to additional losses from denitrification in areas with reducing conditions such as the upper HSC.

DISCUSSION OF CHANGES

The net effect of the above processes appears to be a continuing reduction in the amount of N entering and remaining in the Bay. Higher levels of controls on NOx emissions from both mobile and fixed sources can be expected to reduce N concentrations in both precipitation and runoff. The biggest input of N is from tributary flows and wastewater. Conversion of row crops to forest will tend to reduce both inorganic and detrital N inputs. Higher level of wastewater treatment will reduce the N that becomes available in the bay to support primary production. While new land development is frequently assumed to cause increased runoff with increased concentrations of at least TSS, the data to support the concentration increases are very noisy and problematic, and increased measures to counteract these changes are becoming more common. In any case, development will be a small fraction of the total watershed for the foreseeable future.

We examined the total N concentrations from the largest tributary to Galveston Bay, the Trinity River. In our 1991 paper we found that the USGS gage at Romayor, downstream of Lake Livingston, had an average total-N over the period 1983-1988 of 1.31 mg/L. Of this, 26% was nitrate-N. In the period 1990 to 1997, the data for the same station averaged 1.02 mg/L, with 43% of the N in the nitrate-nitrite form. Because these values are a function of flow to a substantial degree, this difference may not be definitive, and the USGS (1996) did not report a significant decline in total-N concentration through 1993. However, it does suggest attention be devoted to the issue.

With these trends at work it would appear that the amount of N being added to the Bay continues to be reduced, at some cost to society, without a clear benefit being identified. The empirical analysis by Ward and Armstrong (1992) suggests the possibility of a relation between the observed declines in nutrients and measures of Bay productivity. As pointed out by Brock et. al. (1996) there is a great deal of uncertainty in the relation between N input and productivity of desirable species. Nevertheless, N input was considered in setting minimum flow based on what would be needed at current tributary concentrations to meet pre-development N input levels. Preliminary ecosystem modeling in Brock et. al. (1996) indicates that a 50% reduction in N inputs will translate to a 25% reduction in bay N content which presumably translates to a 25% fisheries yield reduction.

We feel the major message of this analysis is the need to keep a focus on the N (and P) inputs to the bay, tracking changes and developing better understanding of the processes that affect productivity. As these studies continue it is also important that we consider the effect of other policies that appear to be reducing the amount of N available to the bay. While we do not yet have the knowledge to practice medicine for the Galveston Bay system, we need to emulate the medical profession and do our best to assure that in our ignorance we do not do harm to the system.

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